so good morning all of you we have come a long way starting with the photoelectric effect which substantiated the idea of planck that electromagnetic radiation can be looked upon not only as a wave phenomenon but also as a quote unquote particle phenomena consisting of quantized packets of energy called photons as i have told you planck himself did not particularly believe in the reality of photons he thought it was only a kind of intermediate step or an effective language to describe what was happening during the interaction of radiation with matter however einstein took this concept very seriously and he was able to explain all the great experiments of herits and lennard and milikan most importantly further experiments by compton completely established that the photon picture is a perfectly valid picture even if it is in sort of disagreement or contradiction with the wave picture and the next step came when rutherford performed his experiments in order to determine the structure of the atom and he gave the planetary model the

so called rutherford model we have discussed that at the great length however the planetary model gave rise to its own problems because the distribution of the electrons around the atom if you imagine that there are orbits like that of planets they were in highly discrete orbits and in particular an atom in the ground state should not have been stable at all according to classical electromagnetic theory because every accelerating charged particle should radiate

so when it radiates it loses energy and when it loses energy it starts falling into the nucleus in particular the most abundant atom that we have hydrogen atom should not be stable in fact you should not have lived or existed for more than 10 to the power of minus 9 or minus 8 seconds after it was formed but we know that the universe is billions of years old

so that was a major problem

so again we see that there is a tussle or a tension between the classical concepts and what experiments are revealing to us very much like what happened in the case of the photon and now the next thing that we studied was that it was the turn of bohr who again brought in the picture of photon and also the concept of quantization not only in the energy of the electromagnetic radiation but also in the allowed orbits

so once the bohr model came then a whole lot of things were understood and in particular the discrete spectral lines were understood the famous lyman bomber passion hund all these series were understood the mysterious constant the red bar constant was simply a combination of the fundamental constants or fundamental parameters mass of the electron charge of the electron prime constant and the speed of light

so everything seems to fall in place

so the next question that we have to ask apart from other important questions is what would the nucleus be made of this is a very very important question for us because all that rutherford scattering experiment revealed it was elastic scattering was that atom consists of mostly empty space electrons can be treated as sort of point particles they are much much smaller than the nucleus and all the mass of the atom is con constrained or contained in a very small volume inside the atom

so let us start with that

so to write a picture of the atom

so we have a nucleus positive charge which is concentrated there and then you have the electron orbits we are drawing it in a plane of course they are all in space and bohr quantization does not tell you in which plane my circular orbit is it really is a material now to give you a scale what we are saying is that

this length is of the order of ten to the power of minus eight centimeters or point one nanometer 0.
2 0.
01 nanometers let us say whereas if i were to magnify this
so i am magnifying this blot this is of the order of 10 to the power of minus 15 meters and this is of the order of 10 to the power of minus 10 meters
so we are speaking of a factor of 10 to the power of 5 or 100 000 between the size of the atom and the size of the nucleus we know that the nucleus contains positive charge for sure because atoms are electrically neutral therefore the big question is what is it that the nucleus is made of and if it consists entirely of positive charge what is it that holds together
so we have a number of questions to ask and to answer and the answer to these questions will obviously come not from merely thinking or hypothesizing we have to do an experiment
so we have to sort of very very carefully go through what is happening
so mind you we are in one shot migrating from a length scale of 10 to the power of minus 10 meters to 10 to the power of minus 15 meters therefore you really need good delicate experiments in order to unravel what was happening and it was really fortunate that in the beginning of the 20th century not very very beginning because chadwick's experiment performed sometime in 1932 around that time we could actually get particles from radioactive decay which could probe the structure of the nucleus not deeply but well enough to tell us what the constituents are
so this lecture will start with the discussion of the constituents of the atomic nucleus whatever is sitting at the center and then we will argue try to argue out what they must be consisting of and what they should be
so whatever i have told you
so far let me again quickly go through in a somewhat quantitative manner
so the first recognition here for us is to realize when we are looking at the fundamental structure of the matter of matter that we have around us we are looking at atoms and nuclei is that there is this remarkable thing called charge quantization there is no logical necessity for charge quantization but nature does exhibit and that is what you are seeing on your screen right now
so what we are saying is that all electric charges come in integer multiples of a fundamental charge unit that is the statement that we are making
so let us denote it by modulus of e because that fundamental charge unit can be either positive or negative we know that there are two kinds of electric charges positive charges and negative charges positive and negative attract each other whereas like charges negative and negative and positive and positive repel each other and of course the experiments involving the cathode rays and the anode rays that is what they demonstrated cathode rays were positively charged anode rays were negatively charged and of course you had the gamma rays which were neutral and which were later identified to be a part of electromagnetic spectrum we have to remember this
so when we say that there is a quantization by that what we mean is that charge cannot the value of charge or the magnitude of charge cannot vary continuously it is not lying on a real number but it can only take discrete values and these discrete values are constrained to be integer multiples of this fundamental unit of charge
so in this picture i have written q equal to n mod e that is what i have written there q equal to n mod a n of course can be equal to zero like in the case of a photon if i look up on it as a particle then it can be plus minus 1 plus minus 2
so on and

so forth you will not find any evidence in any experiment for a fractional charge of course this statement must be made with care because we have some indirect evidence for what are called quarks if we leave them out then that is what we find
so this was something demonstrated by experiments of thomson and d by m mulligan's experiment
so to give you an example electron has a value n equal to minus one because by convention we say that electron is negatively charged proton which is two thousand times heavier in fact i should be very careful about this now i should not use the word proton i shall use the word the nucleus of the hydrogen atom the nucleus of the hydrogen atom has a charge equal to plus one therefore you see the plus one and the minus one cancel each other exactly that is what is happening and therefore the atom is overall electrically neutral and if you go to other elements like helium boron beryllium lithium carbon that is how the whole thing goes nitrogen oxygen that is your periodic table you keep on seeing an increase in the charge number of charges that are setting number of electrons that are sitting in the atom and the corresponding increase in the charge of the atomic nucleus whatever its constituents are and they are exactly cancelling each other
so you move along the row and the periodic table i will show that to you in a minute
so that is what we have shown there is a conventional notation called z and z takes values 1 2 3 etc that does not take negative values therefore the net charge in an atomic nucleus is always a positive integral multiple of the magnitude of the electric charge that is the statement that we are making now of course we need an evidence for the statement that ah the charge of the atomic nucleus is exactly the same as the charge of the electron but for a sign and there is experimental evidence for that and this figure is showing qualitatively for example what is the interaction potential between two atoms
so let us look at that
so what we have is let us say two hydrogen atoms
so this is a hydrogen atom this is a hydrogen atom
so i can put a circle here i can put a circle here this is one hydrogen this is one hydrogen and we know hydrogen exists naturally not in its atomic state but in its molecular state that is what we have from your chemistry course you have learnt a whole lot of it about how the orbits overlap and then there is a binding energy associated with hydrogen atoms
so on and
so forth you have learnt a lot lot about the orbitals in your chemistry course we will not get into that the statement that we want to make is that even if there were a slight excess of charge between these two atoms let us say this was positive this would have been equally positive the net force would have been repulsive and you would not have been able to form an atom at all there is something very very important for us unless we want to make a rather fantastic statement that one hydrogen atom has an excess of one kind of charge and another hydrogen atom as an excess of another kind of charge for that there is no experimental evidence
so that is something that we have
so what we want to say is that this is strictly electrically neutral and this is strictly electrically neutral in fact if you assume a circular orbit or a spherical distribution of charge around the proton you can see that the net charge and the net dipole moment here is zero the net charge and the net electric dipole moment here is equal to zero therefore there should be no interaction at all unless they come very very close very very close now when you

come very very close you can perform a very very small calculation which is not difficult at all let me explain what you have to do

so you have the heavy nucleus here you have the heavy nucleus here at a reasonable distance where they can actually interact with each other and then i am going to write an exaggerated figure i have an electron here and i have a electron orbit here let us say now there is an electron sitting somewhere here there is an electron sitting somewhere here what you therefore do is to write down all possible potentials

so how many such terms are there you have the repulsive term between the two nuclei this is repulsive

so i will denote it as r you can ignore them because they are very heavy and in the equilibrium position when the atom has been formed in the equilibrium position you can take them to be completely stationary you can ignore this particular term then you have the attractive term between the nucleus here and the electron here which is responsible for the formation of the atom and there is an attraction between the nucleus and the electron here which is responsible for the atom

so this is corresponding to the atom there is a repulsive term between the two electrons

so i will call it as an r prime and then you have two attractive terms and these two terms are what are responsible for the formation of the molecule that is what we want to say

so there is a competition between the repulsive term between the two electrons and the attraction between electron of atom one with the nucleus of atom two and the electron of atom two with the nucleus of atom one let us say

so there should be a net attraction which should be able to give me the net force or the binding energy between the atoms

so what do you do you know the radius of the atom you fix the distance and you assume that it is in equilibrium and you slightly perturb and if you make a binomial expansion and sure enough you will see that there will be a quote unquote dipole term

so how is the argument that we are going to make we are going to argue that when this electrons comes very close to this it distorts the orbit of the electron because of the repulsive power my electron tends to go here this electron tends to go here in a similar manner

so there is a dipole moment there is a dipole moment and the two dipoles interact with each other that is the picture that we have and dipole dipole interaction is always between two neutral entities because each dipole is electrically neutral

so please repeat this calculation this is a favorite problem which will be given in all kinds of exams and interviews

so you will do well to work it out if you did that then what is going to happen is that you will see a picture like this very far away you are not going to find any interaction between them at all

so at infinite distance as always i am assuming when the atoms are at rest their total energy is equal to zero

so you see the potential is going to zero very rapidly as they come closer to each other then there is an interaction potential between them attractive potential there is a small binding energy of a fraction of an electron volt a very small energy but if they come too close to each other i am sorry about that if they come too close to each other you see they cannot sit on the top of each other they are hardcore the two electrons will start tripling each other like anything there is also the polio exclusion principle which you would have studied in your chemistry so there is a strong repulsion

so the long and short of the story is that my electron is my distance between the atoms is somewhere here and if you do a quantum mechanical calculation it will tell you what the allowed energies are

so quantum mechanical or non quantum mechanical this is an example of or in fact this is your famous van der waals force 1 over r to the power of 6 minus 1 over r to the power of 7 that is what you are seeing here

so this tells us that the atoms are completely neutral even a slight mismatch would have been given these two problems

so in fact the current upper limits if i remember correctly are the ratio of the charge of the proton to the charge of the electron if i look at this and i subtract 1 from this and if i look at the modulus of this this is less than something like 10 to the power of minus 22 or 10 to the power of minus 24

so the charge neutrality of the atoms is established to an enormous precision up to one part in 10 to the power of 22 that is the statement that we are making

so this is a very important ingredient for us in order to understand the structure of the atomic nucleus we should remember this without this it would have been virtually impossible for us to argue what the nucleus should be composed of now this is not the only evidence for the neutrality of atoms i am sorry this should the

so called equality of the proton and the electron charge or for that matter any other quantization

so this is a picture from an accelerator where two protons at very very high energy of the order of about five trillion electron volts they have collided with each other this picture is taken from the cms collaboration all of you must have heard of the discovery of god particle this is the picture which gave rise analysis of this picture which gave rise to the discovery of the god particle god particle is electrically neutral by the way here you see after the collision thousands and thousands of particles are being produced

so protons will be produced antiprotons will be produced the

so called muons will be produced all of them are charged pi plus pi minus there are lots of charge particles will be produced but all results are consistent with the fact that the total charge is conserved and all of them come in integer multiples of the basic electron charge

so what we are going to do is to take the electron charge to be a fundamental unit

so we say e equal to minus 1 and for a proton we are going to say charge is equal to plus 1 and henceforth we do not have to say my charge is this much in units of coulomb coulomb as a unit is only a matter of practical convenience there is no significance for that but really speaking i should define a coulomb to be the charge contained in

so many

so many electrons 10 to the power of plus 19 or whatever if it is 10 to the power of minus 19 coulombs that is the way we should define and this is what we mean by a natural unit

so we have got a very good evidence for the neutrality of the atoms and quantization ok the next thing that we have to do is to look at the periodic table which was given to us by the heroic work of basically chemists who studied chemical reactions i am not showing you the full periodic table but i am going to show you a section and there are two numbers that you are going to see which is important i hope it is visible to everyone here this is vanadium

so there is a number 23 and there is a number 50.

9415 at this point at this moment please ignore all decimal points is that ok

so we are saying that it has a number 23 and there is a 50 and sure enough if

you count the number of electrons in vanadium it is equal to 23
 so by convention the jargon is that its atomic number is 23 now you can find out the mass of the vanadium atom how do you do that make use of the avogadro hypothesis take one mole of that and ask how many city of that 10 to the power of 23 molecules whatever you are sitting there
 so make use of that and determine the mass
 so if you look at the mass of each of them it turns out to be 50 that is what we have
 so what is the statement that we are making the statement that we are making is that the total number of electrons in vanadium is 23 which is means there are 23 negative charges which means there must be 23 positive charges to compensate for those 23 negative charges in the atomic nucleus
 so but the mass is 50 that is what we have that means those 23 charges are distributed among these in this atomic nucleus which has a mass of 50.
 now if you look at the hydrogen atom for example there is atomic nucleus which has exactly one unit of charge which is compensating
 so if i try to imagine that the atomic nucleus of any atom is built out of that one unit of charge we get into trouble because i have a 50 units of proton mass that is what i have because or the nuclear fundamental nuclear mass because we know that the mass of the atomic nucleus for hydrogen atom is 2000 times greater than that of the electron
 so when i am looking at the mass i can completely forget the mass of the electrons
 so this number at the bottom 50 is giving me the mass in the units of the nucleus of the hydrogen atom and this is giving me the charge
 so you go to chromium
 so i have to go slowly you have to go to chromium there is four and it increases by one unit then you go to twenty five then you see it increases by three units fifty to fifty four
 so on and
 so forth and it goes on and on and the very interesting thing is that the rate at which the mass increases is not keeping pace with the rate at which the charge increases but it is a slightly larger rate you see that here if you were to look at very very slow low mass ah atomic nuclei that would have been different for example here it is forty six and hundred and six seventy eight becomes one ninety five hundred and ten become becomes two eleven
 so in the whole region actually the mass in the atomic nucleus the mass number in the atomic nucleus is roughly twice and in fact it starts becoming more and more than two that is what we are saying this is slightly more than two vanadium but this is on the other hand it is 270 and 110 it is significantly more than 2.

 so in order to understand what the structure of the atomic nucleus is that is what the constituents of the atomic nucleus are we have to resolve the mystery of the mismatch between the charge and the mass that is the statement that i have made and we have to spend some time trying to understand that
 so these are the issues with the atomic nucleus whatever i have described to you
 so far
 so the question that we are asking is where does that extra mass come from what holds the protons together assuming that the nucleus is made up of the same fundamental atomic nucleus of hydrogen which i shall call as a proton which you saw in your cathode rays
 so what ultimately are the constituents of the nucleus this is the question that we have to ask ourselves now there are two possibilities as of today i know

that there are two fundamental particles electrons and protons the nucleus of the hydrogen atom
so i can be conservative and i can argue that the total number of electrons in an atom is not just confined to the electrons in the orbit there is a statement that i can make
so what i will do is i will say that the nucleus consists of a number of protons and the number of electrons
so there are two kinds of electrons rather electrons come in two ways in an atom
so what we want to say is this is the first picture
so i want to imagine let us say that this is my nucleus and this is my atom the full thing there are electrons sitting here
so these i will call atomic electrons and here i can say that what i have is protons which is the nucleus of the heterogeneous atom plus nuclear electrons
so there is a statement that i want to make
so if i go back to this periodic table
so let me look at some random example for instance i can look at tungsten w
so how do we represent tungsten i will write 74 w 183
so what we say is that this is the number of electrons in the atomic orbit and i will say there are 183 protons in the nucleus plus 183 minus seventy four
so that will be thirteen minus four is nine hundred and nine plus seventy four correct electrons in the nucleus
so if this picture is valid it appears as if my nucleus hosts supports shelters more number of electrons than the atomic orbit now this is a consistent picture as far as the charge counting is concerned concerned the other possibility that i have listed is that maybe there is a new electrically neutral particle which is neither electron or the proton or gamma or whatever
so the decision between whether there are electrons in the nucleus or whether are there new kinds of particles can be taken only after looking at experimental details
so we have to perform new experiments and these new experiments were performed by first the curie couple julio curie and mari curie and then it was followed by very very careful analysis by chadwick that is what we are interested in the first picture namely that there are 109 electrons in the nucleus is not probably all that far fetched because in radioactivity people had discovered there is something called a beta decay beta minus dk and you know that electrons can be emitted from inside the nucleus today we understand it as an emission decay of the neutrino neutron and therefore if somebody asserts that 109 probably it is true except that it will give rise to greater complications because there are also nuclei which will emit the anti-particle of the electron namely the positron
so that means we will not be able to fix the number of electrons or positrons at all
so this is based on a primitive idea that you know that all these particles are there and they are coming out and they are not necessarily produced but we should remember that this is not completely ruled out because after all in beta minus t k my electrons are produced that is something that we have to remember before we get into the details of the experiment there is another complication and this again we owe to the careful study of reaction rates by chemists they are the people who gave us the periodic table you have also isotopes corresponding to a given atom
so for example in this periodic table i only showed you for example some iron or molybdenum or ruthenium or rhodium
so on and

so forth it is not as if there is only one species of each of these atoms they can come in many many species avatars

so to say for example if you look at hydrogen chemically there are three species of hydrogen there are very very small differences between them in their chemical reactions but their masses are completely different

so we say there are three isotopes and what are they the corresponding atomic masses is that ok the bottom number are given by one two and three that is to say all these three species of the hydrogen atom have only one orbital electron and we know that orbital electrons are responsible for chemical reactions the nucleus does not participate in chemical reactions

so they all have the same atomic number that is what we have they have a name hydrogen deuterium and tritium that is the statement that we make if you look at carbon whose atomic number is six that is there are six orbital electrons then there are it comes it has again three isotopes there could be even more but they would be highly unstable twelve thirteen and fourteen that is to say the mass of the nucleus can be either twelve or thirteen or fourteen

so we have to understand that then you have this great nucleus called polonium which was discovered by mari curie in her studies on radio activity

so when she had to give a name for this new element she remembered her native country country of her birth the motherland

so she called it polonium in honor of poland that is what she did disc has 33 isotopes with the atomic mass ranging from 186 to 227 the stable one is probably around 200 the most stable is probably around 200 or 210 or some such thing never mind about that

so in proposing a model for the atomic nucleus we should also be able to explain what is happening with these isotopes isotopes are a very very important they are very very important constituents of the periodic table although they may not be shown in a standard periodic table because it is not easy to show them ok

so it is here that the experiments of chadwick become very very important he was a student of rutherford and rutherford had actually speculated that the nucleus consists of new kinds of neutral particles and rutherford went on to perform careful experiments not only did he perform careful experiments he also went on to do a very careful analysis of his and other experiments to decide what the matter is ok

so the idea is to repeat the experiment of rutherford but then now we are not going to look at elastic scattering but you look at inelastic scattering

so what we do is to look at elastic and inelastic scattering

so what would be an elastic scattering what would be an inelastic scattering

so in an elastic scattering for example total kinetic energy will be conserved all of you know it from your mechanics course and total momentum is of course conserved this is an example of elastic scattering in the rutherford experiment you had the gold nucleus you had your alpha particles and it was getting scattered like this that is what was happening if you ignore the recoil of the gold nucleus because gold is very very heavy otherwise you can also take that into account there is no problem about that then when i say that this scattering is elastic we are asserting that the energy of the alpha particle remains constant throughout

so what are we saying it started at infinity it goes to infinity

so at t equal to minus infinity or at t equal to plus infinity it is at a very very large distance away from the nucleus therefore there is no interaction between them that means the incoming kinetic energy e initial kinetic energy is the same as e final final kinetic energy and we say this is elastic scattering

so what is happening in such a process is only a transfer of the momentum and not transfer of energy that is a very important thing well if energy is conserved how is momentum getting transferred the magnitude of the momentum is the same but it is only the direction that is changing

so that is what we say if i were to draw a line here you see the momentum transferred the scattering angle is somewhere sitting here is that okay that is what we have this is an example of an elastic scattering i can also look at inelastic scattering these experiments also you are familiar with as we discussed that at some length in frank hertz experiment for instance what would be such an example

so let me give a hypothetical case i have an atom let us say and there is an electron sitting in the ground state now what happens a photon comes radiation comes what it does is to give a part of the energy to the electron

so that it can go to the first excited state that is what is going to happen and then the rest of it is going as a scattered radiation now you see your energy part of the energy is given to increase the internal energy of the atom the atom is still at rest overall momentum is equal to zero let us say and then the if you look at the final energy there is not only a momentum transfer there is also an energy transfer oh well not only you can actually give an electron to the send the electron to an excited state you can actually ionize that that is your photoelectric effect

so it will flow will come out

so this is my photo electron

so clearly here if i look at the scattered photon it will have a less energy whatever is given by the difference between the initial and the final corresponding to the kinetic energy of the photoelectron plus this

so in all these cases we say that the interaction is inelastic because the kinetic energy is not a conserved quantity you have given it to internal energy or to eject or to break a system or whatever

so what chatwick essentially did was to perform an experiment by bombarding light elements with alpha particles rutherford did an experiment with heavy particles but chadwick bombarded them with light light elements in fact he went all the way from hydrogen to oxygen if i remember correctly its one of the most beautiful experiments that were performed the preliminary results i think were reported in nature and then he produced a published detailed paper in proceedings of royal society he was a british physicist

so what you do is that curie had already discovered the radioactive properties of polonium and polonium decays by emitting alpha particles in fact the dominant decay is alpha particle to start with and at some point we will work out the charge mass balance

so as i told you polonium has an atomic mass in the range of about 200

so this decays by emitting an alpha particle all isotopes of polonium actually decay they have different lifetimes

so you should be intelligent enough to use the right isotope which has a small lifetime that is what you do and the energies range from something like 5.
5 millia electron volt to about five point eight let us say six six million electron volts

so these are good numbers i would ask you to remember these numbers because we are going to use them later when we look at the binding energy of the nucleus these numbers are interesting

so what curie julio curie and marie curie did for the first time and later by chart week was that to make use of these alpha particles of this energy and bombard light atoms

so we have gone all the way from hydrogen to oxygen let us say oxygen has an atomic number of eight if i remember

so that is what i have
so you have hydrogen helium boron beryllium lithium carbon nitrogen oxygen
so these are the atoms that we have he did very very careful experiments and studied what was happening as an end product this this is the experiment that they perform
so when you perform the experiment what you do is to in order to find out what the produced particles are the first thing is that nucleus gets broken
so the most important experiment of chadwick was on beryllium because it showed the most spectacular effect
so let us stick to beryllium for example soon after the scattering beryllium itself cease to exist
so we have come a long way we started with the question whether atoms are unbreakable they are infinitely hard and now we have gone to the nucleus and we find that nuclei can also be broken this of course is very very important because we know that there is both spontaneous fission and artificial induced fission and induced fission is what is responsible for our atomic reactors which produce whole lot of power and also the destructive weapons there is also another process that takes place in fusion which we will study at a later time
so anyway the beryllium gets broken and what comes out
so what are we saying you want to know what is inside this ball break the ball you want to know what is inside the room break the ball that is the statement that we are making
so this was done by both the curie couple and mr chadwick that is what we did
so when it happened what happened was that when that scattering new radiation was observed now i am deliberately using this word because today we preserved the word radiation for electromagnetic waves but those days it was very difficult to distinguish what it was whether it is an electromagnetic radiation or some other neutral particle
so anything that came out of a nucleus was called radiation alpha radiation beta radiation gamma radiation
so that was the word that was used and this radiation consisted of two components charged and neutral
so how do you know that it consists of two components the experiment is very simple you whatever is coming out you apply a magnetic field the charge fellows will all bend and go away
so so let us say that there is you have collimated the quote unquote radiation emitted from the disintegration of the beryllium nucleus let us say
so this is a collimated then they enter a region of magnetic field okay then the charge particles will start bending let us say in this direction if there are negative charge particles they should probably bend in the other direction let us keep that also in mind and then what i will do is i will make them interact with a gas this is the typical setup of the experiment or it need not be a gas it could be paraffin for example it has to interact with matter that is what you do you can put your targets here also no harm
so that i can understand the interaction with all the species that is what you find sure enough you found that there are lot of them which are bending in one particular direction
so no surprise about that that means there are charged particles and these charge particles after bending when they interact with matter it could be either with a hydrogen atom or it could be with paraffin or whatever they simply showed characteristics of interaction of cathode rays with matter which were independently studied
so what do you do your ionized hydrogen atom that is your fundamental atomic nucleus whatever you see you see the same thing happening here except that your

statistics has improved of course the energies are different that is what you have
so you simply identify them with protons
so no nobel prize for this because the curvature whether it bends this way or this way because you know the velocity will give you the charge in fact you can find e by m which will tell you what the masses of these quantities are but then there are these neutral particles which are coming here that is very very important for us how do you know that they exist because they do not respond to your magnetic field what you do is if you put again a paraffin target or hydrogen gas or whatever these are found to have a great penetrating power and they can actually knock off lot of electrons in fact this neutral radiation can actually interact with the nucleus and further break them
so this is the fundamental observation of the query couple julio curie marie curie and also that of chatwick
so that is the statement that we are making
so this slide essentially summarizes whatever i was describing to you all this time
so what it says is that the bombarded nucleus gave rise to two kinds of species protons and neutral radiation neutral radiation had enormous power that is a very important thing for us in fact it was greater than the penetrating power of any known x-rays x-rays were known to be the really most powerful radiation which you produced
so it was greater than that and they could eject electrons and the number of protons i am sorry it is wrongly written here from a number of hydrogen atoms they could eject them
so the question was what was this neutral radiation made of more remarkably you find that there was no evidence for any negatively charged particle
so my original hypothesis said that probably my atomic nucleus consists of what positively charged particles and negatively charged particles which compensate for the excessive positive charge then they should have been bent here and their e by m ratio should have corresponded to the e by m of the electron because that is the hypothesis that we made in fact absolutely no evidence for found for that
so you can simply junk the hypothesis that there are electrons sitting inside the nucleus which is very good because now we have to explain where these electrons came in the case of beta t k but at least we do not have the embarrassment of trying to say that my nucleus consists of everything under the sun proton electrons positrons and i cannot fix the number i do not have to worry about that that is what we have and this is what we have to fix i have almost come to the frag end of my story today how are we going to interpret this julio curie and mari curie assumed that what was being emitted was photon that is what they assumed and there was already an evidence for photon matter scattering i think i have discussed it earlier let me explain that to you again
so soon after photoelectric effect compton discovered compton effect this is very very important for us and for the first time compton effect demonstrated that photons carry not only energy but also momentum
so what is the experiment here you assume that the electron is practically at rest and you send a radiation of frequency nu and you look at scattered radiation you find that the scatter radiation has a frequency in u prime this is the experimental finding and you also look at the scattering angle theta that is what i have
so imagine there is a collimated beam of light which is coming then there is an electron which is at rest now what i am saying is that i look at the angular distribution of the scattered radiation
so if i were to replace this picture by a particle picture it is as if this

electron this radiation came and got scattered here this fellow was initially at rest but then it will get scattered and it will move in this direction that is what happens correct because when there because total momentum and energy should be conserved now in order to understand this compton invoked the photon picture and he said that my energy of gamma is given by h nu and the photon momentum the momentum of gamma is evenly given by h nu by c that is what he said and this is something that we have discussed at great length now you can imagine compton scattering is elastic scattering between photons and electrons

so if my radiation is coming and going in the forward direction then there is nothing that is happening the maximum momentum will be transferred to this electron and therefore energy will be transferred to the electrons at large angles

so all that you have to do is to write your momentum conservation equation for whatever particle that you wrote therefore that will give you a definite relation between the lambda of the scattered photon which i will call lambda prime and the angle at which my photon is scattered that is your famous compton formula right h by m c into one minus cos theta that is the number that you are going to get

so compton scattering had been very very well established because we are speaking of experiments then in nineteen thirty nineteen thirty two

so taking a conservative approach marie curie and julio curie assumed that the neutral radiation was nothing but the photons which are highly energetic now this gives rise to a number of problems because it will not explain to you the neutrality of the atom they would have had to worry about that but chadwick what he did was to perform a very careful analysis of these experiments

so for example he looked at this neutral radiation which is coming he looked at the scattering of this neutral radiation with nitrogen he looked at the recall momentum of the nitrogen nucleus he did the momentum balance and he argued that the conservation laws which are very very basic to us which are fundamental us what are the conservation laws energy conservation and momentum conservation they are consistent if and only if we assume that the neutral radiation consists of electrically neutral massive particles he showed if there are photons they would be coming with an energy of 50 million electron volt and the energy conservation would go away

so to cut the shori start short i am not going to do that analysis with this very very careful experiment chadwick concluded that there must be a new neutral particle which is roughly the same mass as that of a proton

so mn whose mass is 1.

15 times the mass of the proton that is what he gave with a ten percent error that is very very important because you are rating 0.

15 which is roughly 15 percent

so you are speaking you know it could be very small also compared to the mass of the proton whatever changes and today the current value is mass of the neutron is one point naught naught one times the mass of the proton given the experimental situation and given the uncertainties and given the kind of statistics they were looking at it is very clear to us that what chadwick achieved was something very very remarkable of course subsequently its magnetic moment was discovered

so on and

so forth therefore now our task is to accept neutron as a new fundamental particle a new particle which is a constituent of the nucleus we can do away with the concept of electron in the nucleus and study the properties of atomic nucleus which we will take up in the you